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ABSTRACT

Several issues in science education are examined, including those related to the current concern about science education in schools, the basis for a reform in science education, technology in the science curriculum, redirection of the science curriculum, uses of knowledge, decision making in human affairs, organization of the curriculum, and science and vocational education. It is suggested that much of the confusion on these and other issues arises from a failure to recognize that the purposes of science education are changing, that new subject matter is being introduced, and that the context of the curriculum is shifting from that of the disciplines to human affairs. This new view of science education as a common education in science and technology is compared with prevailing views of science education programs as they exist in schools today. Areas compared include rationale and goals of science education, subject matter, cognitive processes, value and ethical considerations, textbook role, and the type of understanding fostered by instructional strategies. For example, current goals for teaching science are internal to scholarly fields of scientific research while goals related to the new view are based on scientific and technological systems in social, cultural, and individual contexts. (JN)

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Reforming Science Education: The Search for a New Vision

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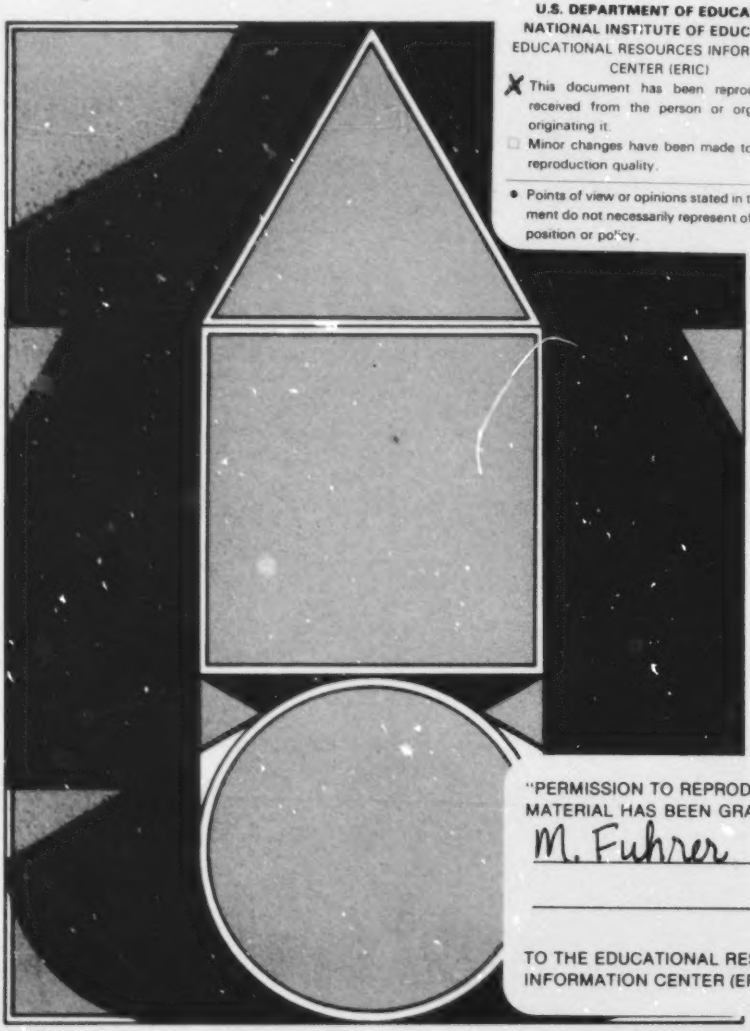
By Paul DeHart Hurd



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Council for Basic Education • Washington, D.C.

Reforming Science Education: The Search for a New Vision

By Paul DeHart Hurd

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INTRODUCTION

Ironically, while science and technology have become increasingly dominant forces in our culture, science education in our schools languishes.

Long gone are those post-Sputnik years when science education was, in fact, the cornerstone of one of our more conspicuous education reform movements. At that time, not only was curriculum reform in science a major industry in itself, but an education in science was considered to be an essential part of being an educated person.

Granted, much of this interest was motivated by the sheer competitive spirit that followed the Soviet launching of Sputnik. Nonetheless, the current neglect and disarray of science education is particularly disturbing.

As a number of the recent reports on education have pointed out, scientific literacy is essential today for this country's progress, economic growth, and national strength. But far more important, an understanding of science and technology is absolutely critical for enlightened citizenship.

America has become a highly scientific and technological society, and our most pressing economic, political, and social issues emerge from this new reality.

But what is it students need to know in science? How should it be taught? How should the curriculum be structured?

For advice on these and other issues, we sought out Paul DeHart Hurd, who has devoted a long and distinguished career to science and science education. For 25 years, Dr. Hurd taught science in junior and senior high schools; for 24 years, he was Professor of Science Education at Stanford University. He is the author of *New Directions in Teaching Secondary School Science*, (published by Rand-McNally) and has contributed extensively to scientific and education journals and magazines.

Dr. Hurd has answered our questions about science education with great clarity and perception. We believe that *Reforming Science Education: A Search for a New Vision* will be indispensable for science educators and indeed for anyone interested in improving American education.

Reforming Science Education: The Search for a New Vision

Where there is no vision,
the people go unrestrained . . .

Proverbs 29:18*

. . . the ideal of human service is the
ultimate goal of scientific effort.

Francis Bacon, 1620**

Why the concern about science education?

For some time now, the public press has been reporting that science education in the United States is in disarray. The evidence it frequently cites to support this contention, although usually one-sided and oversimplified, is still sufficient to cause deep-seated concern among both the public and educators about the credibility of our current school science programs.

The evidence includes a number of disturbing trends:

- decline in science enrollments in secondary schools;
- neglect of science teaching in elementary schools;
- unfavorable attitudes toward science acquired in the junior high school;
- drop in achievement test scores in the last decade;
- decline in the number of students aspiring to science careers;
- shortages of qualified science teachers and the likelihood the situation will worsen;
- low priority assigned by parents to science education;
- failure of science education to respond to changes in science and technology; and
- confusion on the part of educators about the goals of science education.

**New World Translation*
Brooklyn: International Bible Students Association, 1960.

***Hugh Dick (ed.) *Selected Writings of Francis Bacon*
New York: Random House, 1955.

And so it goes, each new report adding more information to this dreary assessment of science education. Predictably, there has been a public outcry for immediate corrective actions. But what is the problem?

The first impulse has been to find someone to blame for the predicament, rather than to explore basic causes. Teacher ineptness has been made the scapegoat for much of what is considered bad in science teaching. Principals are accused of poor leadership, and parents of not caring what happens in their schools. Science departments and schools of education in colleges and universities are charged with not properly preparing science teachers. Legislators at the national, state, and local levels are criticized for their failure to provide sufficient financial support for education. Students are viewed as lacking interest and motivation for learning. Business and industry complain they are required to spend billions of dollars per year teaching new employees basic mathematics and communication skills that should have been taught in the schools. Higher education institutions are portrayed as remaining aloof from the educational problems of schools and failing to provide expertise. The federal government believes that schools are jeopardizing the technological productivity of the nation and threatening its competitive position in the world economy. Individual analysts agree that the science courses are lacking in rigor, badly taught, and uninteresting to students, and that something should be done to improve conditions. But what is it that should be done?

Nearly every state and many school districts have already formed task forces and proposed changes in policy and practices to improve science education. The most common proposals to bring about "quality" and "excellence" in the schools are: extend the school day and year; require students to take more courses and make courses more rigorous; raise educational standards for new teachers and retrain less qualified teachers now in the schools; lower the professional requirements for certification to alleviate teacher shortages in science and mathematics; require academic proficiency examinations to qualify teachers; demand that students pass a comprehensive science examination for high school graduation; raise college and university admission standards; reward the "best" science teachers with salary increases and make all salaries competitive with industry; involve parents and representatives from business and industry more actively in schools; provide more money to schools to raise teacher salaries, improve

laboratory facilities, and hire teacher aides; increase the number of computers in schools; begin formal schooling earlier than six years of age; establish magnet schools to increase diversity of student choices; publicize "good" schools; improve the organization and management of schools by using accepted business practices; evaluate management and supervision skills of principals; and provide forgivable college education loans for students who prepare for science teaching careers.

In one way or another, each of these efforts can initiate, influence, or bring about changes in educational practices, but they cannot provide appropriate direction for overall educational reform. The ills of education are not likely to be corrected by such measures. Mandating changes in class sizes, extending the school day and year, adding more educational technology, and requiring more testing do not constitute effective educational reform. Furthermore, no mass of empirical facts on the status and condition of science education will isolate the basic problems that currently beset science education.

The basis for a reform in science education

Our basic concerns about science education originate mostly in conditions that lie outside the school—namely, changes in the social framework in which the sciences and technology are embedded, changes in the relation of science and technology to each other, and the desire of people for a higher quality of life. These are the conditions that signal our need to reconceptualize what an education in the sciences should mean. The most compelling argument for reforming science education is that science teaching is currently not responding to the intellectual and knowledge demands of a science/technology oriented society. The proposed agenda for reforming science education would bring it into harmony with the way science and technology relate to human affairs, social progress, and the wider culture.

The nation is now experiencing a widespread cultural transition propelled by advances in scientific knowledge, technological developments, and shifting economic and social patterns. New conditions in science, society, and technology are raising wholly new questions about the purposes of an education in the sciences and about what is worth knowing. The public outcry for a reform of schooling in America is, in fact, a demand for a clearer image of what science education should be tomorrow and in the years ahead.

This controversy is taking place at the very time that extensive efforts are being made to redefine the social contract between science, technology, and society, an endeavor that has been going on in the United States for over a half-century but has now become critical to our economic future. To improve science education, we need to consider this growing unity of science, technology, and society.

Moreover, the emphasis is now shifting to a view of technology as a means for advancing science, improving the quality of life, and meeting economic challenges. The focus is on what science and technology can do for individuals and the country now, as well as assuring the future progress of the nation.

A common charge against school science is that it does not meet adequately either the intellectual or the knowledge needs of present-day citizens. Modern America is increasingly a society largely driven by advances in science and technology. Science, technology, and society exist today as an integrated system for advancing the economic productivity of the nation and the well-being of its people. The success of the system depends on a general population that has an understanding of science and technology in a social context. People not so informed represent the new disadvantaged in society. The reform sought in science education is to make it more responsive to the broad needs of the nation as well as to the welfare of its people. Science courses as they now exist in schools are perceived as too narrow in view, and the subject matter too professionalized to serve national purposes and individual needs.

The projected reform of science education aims to achieve a conceptualization of science education that will provide students with a more unified view of the natural sciences and their relation to human affairs and national life. To help bridge the gap between the world of the scientists and that of the non-specialists, concepts of technology and engineering would be integrated into science courses, which is more in harmony with the way students are likely to experience science. An understanding of science and technology in a civic-cultural context better serves human purposes, as well as the public good.

Developing a science curriculum that recognizes the pervasive role of science and technology in human affairs and how they serve society differs from the traditional pattern for restructuring science courses. These efforts at curriculum reform in the sciences concentrated on refining individual courses to accommodate the

current state of particular disciplines. The procedure was to update the factual information in science courses, readjust the theoretical constructs for interpreting the facts, and strengthen inquiry procedures with improved laboratory experiments.

Every 20 to 30 years, the process has been repeated. Each time the goal was to assure that a precollege science course would accurately portray the structure of a discipline as perceived by researchers in the field. The educational goal was to include in the new program the subject matter, inquiry procedures, and laboratory activities important for educating students who might choose careers as researchers in science. The result has been a precollege science curriculum with the goals and a diluted version of the subject matter of university courses.

In the 1980s, the central issue we need to resolve in reforming science education is the context for the teaching of science. The discussion must now center on the potential of science instruction for developing intellectual skills, and for using scientific and technological achievements in human affairs, both individual and civic.

If we are to view science and technology as a basic in the education of all youth, they should have personal and socially oriented objectives and much to do with the way we live our lives. To achieve these objectives, we will require courses with a knowledge base that enables students to recognize, interpret, and make intelligent decisions on matters of science and technology that influence their lives.

In the next sections of this essay, I will deal with some of the newer and crucial aspects of the science education reform in more detail.

Technology in the science curriculum

To bridge the gap between science as a research endeavor and science as an enterprise of human service, issues of technology should be incorporated into the science curriculum. This change is not simply a matter of adding a few examples—robots, computers, diesel engines, medical implants, and artificial hearts—to science courses to illustrate how technological products work. The change we propose is one that presents the interdependence of science and technology and the ways in which they will continue to influence our cultural, personal, social, economic, and political affairs.

The modern concept of technology does not have a precise and

scholarly definition that is acceptable to all who study its nature. There is not a word in the English language that represents the symbiotic relation that exists between modern science and technology, though it does have characteristics that can be described.

In pre-1960 science courses, technology was treated in terms of inventions or industrial processes: the structure of a jet engine in physics, steel making processes in chemistry, crop rotation in biology, and weather balloons in general science. In the 1950s-1960s, the authors of the federally funded innovative science curriculum projects omitted notions of technology in the textbooks they produced. In contrast, the 1980s reform of science education must promote a balanced and interrelated presentation of science and technology in all required science courses from elementary through secondary school.

In modern terms, technology refers to a system that combines science and technological innovations and social arrangements in ways that give people greater control over nature and human affairs and the direction of our society. Innovations in science and technology change the character of our culture, the way we live, our patterns of thinking, and the shape of the economy. The development of modern transportation systems (automobile and air travel), rapid communications systems (radio, television, telephone), medical advances (X-rays and artificial life support systems), and the use of robots and computers in industry illustrate the extent to which advances in science and technology have changed human experiences.

Though science and technology act as an integrated system, they are not synonymous in meaning. Science is a way of knowing; it is a breeder of new knowledge. Scientists, who pursue knowledge for its own sake, are motivated by their curiosity to learn how and why nature behaves as it does. Their satisfaction arises from discovering new facts, formulating new theories, and developing predictive laws that their peers consider significant in advancing a science discipline. The results of scientific research are judged on the basis of their integrity, not their usefulness in practical ways.

The fascination with science lies in its ability to give us a greater understanding of the natural and physical worlds, and in the intellectual power of its predictive laws. There are laws that tell us what is likely to happen at some future time under specified conditions. For example, we can be quite certain about what will happen if appropriate chemicals are allowed to react, or what direction our body will take in leaping from a cliff, or what will

happen to a green plant left in the dark too long. The way in which scientists carry on their work varies enormously. There is not a single scientific method, only a dedication to search for knowledge by whatever procedure seems useful.

Technology, on the other hand, is a process that seeks new uses of knowledge. Technologists work with a definite purpose in mind, such as designing a more fuel-efficient airplane, an "intelligent" robot, improved cancer therapy, safer roads for travel, synthetic insulin, and communication satellites in outer space. The work of the technologist responds to industrial and social needs and whatever product or process people might find useful. Technologists sometimes discover new knowledge, but mostly their work consists of finding practical uses for the knowledge scientists generate.

> *To use scientific and technological information properly requires that students have some idea of the intellectual worthiness or validity of knowledge. The student should be able to distinguish evidence from propaganda, probabilities from certainties, questions from pseudo-questions, rational beliefs from superstitions, science from quackery, data from assertions, science from myth and folklore, known from what is not known, credible from incredible, sense from nonsense, fact from fiction, and theory from dogma. These insights into the nature of information are critical, and they represent an aspect of student learning that is essential if we are to employ the subject matter of science courses to bring about rational thinking.*

Technology has a longer history than science, dating back to the first slingshots and sharpened stones that improved the hunting efficiency of primitive people. Only in recent years have technology and science become closely associated. Although technologists may develop their innovations independently of a science base, their endeavors can never override scientific laws. A perpetual motion machine is not a possibility because it would violate the first law of thermodynamics.

The methods used by technologists to develop new processes or products are no more uniform than those of science. The worthiness of a technological innovation may be quantitative. For example, a machine works faster, lasts longer, and is more economical to operate, all of which are attributes that can be measured and compared. We can also judge achievements in technology in quali-

tative terms, on the basis of their aesthetic characteristics, ethical implications, convenience, potential danger to people and the environment, and enrichment of human activities.

Sometimes the one must be balanced against the other. For example, a car that is economical to operate may not have the styling most people prefer, and therefore it does not sell. Or, skin patches to deliver drugs to the body are unquestionably a convenience, unless you regard the technique as too expensive. Or, chemical insect sprays, inexpensive and effective though they may be, may not be considered desirable because they have a potential for causing cancer in people.

An important question we must consider in any curriculum reform is: What are the educational advantages to be gained by the proposed changes? A related issue is: What benefits will accrue to society in the long run?

We add concepts of technology to the science curriculum with the following advantages and expectations in mind. They will:

- Raise the motivational level of students, since technological innovations are more common in their experience than scientific advancements;
- Bring students into direct contact with scientific and social problems, dilemmas, and predicaments that they have a responsibility to help resolve, such as health practices, use of energy resources, and environmental management;
- Provide a context for developing scientific literacy. Scientific literacy is not a direct outcome of learning science; it evolves from situations in which there is an interaction of science, technology, and society;
- Make opportunities available for students to develop a wider range of intellectual skills than they would from the study of science alone. These skills are related to decision making, systemic thinking, the qualitative analysis of problems, and making ethical judgments;
- Offer a context for teaching the interplay between science, society, the humanities, people, and nature. Technology has a greater capacity to integrate subjects in the total school curriculum than does science by itself. It links the natural and social sciences and mathematics;
- Provide a way for students to develop insights into planning, shaping, directing, and carrying out changes in human and social affairs. The study of technology has an action and a forward component that is not present in traditional science courses. For exam-

ple, a study of genetic engineering leads to the possibility of minimizing genetic diseases, increasing the biomass as a future energy source, modifying crop plants to grow in now unsuitable soils, and using bacteria to manufacture medicines.

Primarily then, we add technological consideration to the science curriculum to increase student motivation and to make science courses more responsive to individual and social affairs.

Redirecting the science curriculum

Curriculum reform should be guided by the educational purposes we wish to achieve. The direction of the reform described here is one that leads to a responsible and enlightened citizenry in science and technology. A curriculum focused on effective citizenship must be developed in the context of the common culture, democratic values, and human affairs.

Science education as a basic in American schooling implies a core of essential learnings and intellectual skills important for all individuals to possess. We assume that every citizen should have the opportunity to participate in resolving public issues that pertain to the common good and the welfare of the nation. We assume that the health of a democracy depends on a national unity of purpose, shared values, and a background of common knowledge. A basic curriculum in the sciences is one that recognizes our common membership in the human family; our shared perceptions of the natural world; our collective responsibilities to society; and the universality of scientific laws, theories, and concepts.

A substantial number of problems and issues that currently face the nation require an understanding of science and technology and collective action to resolve them. Consider, for example, health, energy, economic productivity, the quality of life, and the stability of our natural environment. If we are to make progress in dealing with these problems, citizens as a whole must have an appropriate background of knowledge, intellectual skills, and experience that will improve the quality of discourse on these issues. In this sense, the notion of a common curriculum represents a belief that it is downright dangerous for a nation today to have a citizenry that is ignorant of science and technology.

A common curriculum in the sciences assumes that there are common goals throughout the country derived from a conceptual framework—one that has a consensus of national support and subject matter validity. A common curriculum, however, does not mean that all chemistry courses in the United States would be

identical in subject matter or course organization. Different adaptations of the science concepts to reflect local applications and interests are to be expected. For example, if health and physical fitness is a national education goal, local conditions will influence which particular factual information and instructional conditions are best suited for achieving that goal. Individual teachers, using quite different methods and materials, would still have a responsibility to teach this paricular concept State or national achievement tests would provide information on the degree to which the students grasped information on the concept, regardless of the background information they received. The "common" of the common curriculum is found in its goals, ideals, values, and intellectual skills—not in the uniformity of its subject matter and teaching procedures.

Nevertheless, science courses in schools are currently far more uniform than we generally recognize or admit. In every science subject, two or three textbooks account for nearly 75 percent of the sales. The factual information in different textbooks of biology, physics, or chemistry is much the same; standardized achievement tests and college entrance examinations help to keep it that way. Furthermore, state-adopted or
-recommended textbooks assure regional uniformity of subject matter. And required courses carry the implication that the subject matter is important for every student. As a result of these conditions, we have an "unofficial national science curriculum" in terms of the uniformity of scientific information, but one that is embedded in a confusion of intent and purposes.

The movement for reforming science education centers on clarifying instructional goals and setting public policy on general education in the sciences and technology. The current emphasis on a common curriculum is a move away from the hodge-podge of science courses and the confusion about educational purposes that characterized science teaching in the 1970s. Instead, it represents a move toward greater national unity and educational equity.

The use of knowledge

Today, according to a common slogan, we are living in the "information age." In fact, our ability to make use of information fuels our economy and helps us adapt to rapid changes. According to recent estimates, more than half our gross national product is derived from the development, storage, processing, and dissemination of information.

In the reform of science education, a major goal that has emerged is to use knowledge and bring it into action. To reach this objective, students will require intellectual skills not commonly taught in science classes today. "Quality" in science education is not to be found in the amount of information that learners can recall, but in their ability to process and apply information in posing questions, analyzing issues, and making decisions. It is one thing to be informed about science and technology; it is quite another to be able to use information in the context of human reason.

To use scientific and technological information properly requires that students have some idea of the intellectual worthiness or validity of knowledge. The student should be able to distinguish evidence from propaganda, probabilities from certainties, questions from pseudo-questions, rational beliefs from superstitions, science from quackery, data from assertions, science from myth and folklore, known from what is not known, credible from incredible, sense from nonsense, fact from fiction, and theory from dogma. These insights into the nature of information are critical, and they represent an aspect of student learning that is essential if we are to employ the subject matter of science courses to bring about rational thinking.

If students are expected to use in human affairs what they have been taught, then what they are taught must have this possibility for use. Reform in science education must include sorting out from all that is known about science and technology the subject matter that is most likely to be critical in the civic, personal, and intellectual affairs of citizens.

In selecting this body of knowledge for any science course, we should involve specialists, not only in science but in the social sciences, mathematics, engineering and the humanities. Knowledge confined to one discipline is too narrow in scope to be the sole basis for dealing with either science and technology, social problems, or problems of the individual. People in the social sciences and humanities must share in choosing the knowledge in science that has social and cultural importance. A fair amount of the subject matter for a science course, however, should include that which illustrates the basic principles, theories, methodology, and conceptual nature of its parent discipline. Without this background, students have no way to judge the validity of the information they will be using.

Raising the quality of science education means, among other

things, improving the quality of what is learned. To be useful, knowledge must be taught in operational terms. Learning the composition of carbohydrates, fats, and proteins will mean more to students if they consider the physiological properties, and learning will be further enhanced if this study is linked to the subject of their personal nutrition. Knowledge is a state of understanding that transcends the learning of isolated facts, definitions, names, and symbols. Information becomes useful when it is at the level of a concept, law, principle, generalization, or simply an idea. In most courses, science is taught more as a vocabulary than at a cognitive level that has a potential for critical thinking and application.

Certainly one of the most important objectives of science curriculum reform is to enable students to use what they learn to acquire even more knowledge. Extending one's knowledge on a subject depends on whether what has been learned before can be interpreted or applied. Discrete facts do not have value in interpretation or application; concepts and principles do. A few concepts and principles well understood are to be preferred over the literally thousands of facts found in most science courses which only serve to dilute understanding and which will never transcend the classroom, promote intellectual insights, or generate more knowledge.

The ability to process and use information depends not only on selecting the appropriate form of knowledge but also upon certain cognitive abilities, namely problem solving, decision making, and logical reasoning. These processes of thinking depend upon knowing how to analyze, synthesize, use quantitative measures, and make quantitative and qualitative interpretations. In turn these processes depend on such skills and operations as observing, describing, comparing, experimenting, making reasonable guesses or hypothesizing, drawing inferences, finding relationships, recognizing variables, isolating a problem, making judgments and interpretations, locating valid sources of information, extrapolating, identifying and evaluating experts, and questioning. How the attributes of thinking, problem solving, and decision making are combined and applied depends on the nature of the problem and the available information. There is neither one single procedure for thinking, nor a scientific method, nor a formula for problem solving that is generalizable to all kinds of problems. In the study of most problems, we encounter limitations of method and information, as well as different interpretations of findings. Interpreting the findings on a science/technology problem may

involve rational, personal, social, and ethnical considerations in unequal proportions. Thinking and other cognitive processes are not something to be learned as isolated skills, but to be developed by working on an array of problems in the context of science, technology, society, and human values. Examples of problems in this context are the supply of world food resources in relation to population growth, or the use of lasers in medicine and industry and possibly as a weapon of war.

Decision making in human affairs

A distinguishing characteristic of the current reform in science education is its focus upon the citizen as a non-specialist in either science or technology. In our civic and personal affairs, the cognitive processes that we most frequently use are those of decision making. Practically every day we are faced with a choice of actions that require a knowledge of science if we are to make a responsible decision. Such decisions may range from a consideration of whether to purchase megavitamins, support pollution controls, buy a home computer, avoid "junk" foods, or contribute funds to cancer research. The educational goal, then, is to teach students how to marshall, organize, and analyze information leading to a choice of action and to recognize the probable consequences. But the making of personal and social decisions is not simply a matter of gathering and weighing the appropriateness of facts and making an inference. Solving problems, be they social, cultural, or personal, entails other considerations such as: What are the degrees of probability, risk, uncertainty, cost, and benefit? Who wins and who loses? What will do the most good? Which actions are plausible and which are probable? Which action is maximum and which is optimum? What is appropriate and what is acceptable? What is reasoned and what is intuitive? Does the problem stand alone or is it related to other problems? Which action is logical and which is based upon ethical judgments? What is the best action, and what is good enough?

Our decisions are also influenced by our past experiences, intuition, and sense of values. These factors can influence how we view a problem or interpret it. The mining of oil shale is to one person an aesthetic issue that arises from the scarring of the landscape; to another individual it is a solution to the energy problem. One way we can measure the quality of a science curriculum is by determining the extent to which students gain experience in dealing with real-world problems of science and technology. In the process, they should come to understand the importance of valid

information in the sciences and technology, and the limitations of knowledge.

New advances in science and technology require decisions that must be made about their use. Science education should not avoid these value and ethical judgments, but instead should examine and analyze them in terms of valid scientific or technological information. The teacher's responsibility is not to instill a particular set of values in students but rather to encourage them to debate values and use rational processes for making judgments. We cannot expect that two equally informed students will make the same value interpretations. Values and ethics provide the basis for social responsibility as science and technology change personal and social options. Consider the question of using robots and computers in industry. On one hand they are justified for taking over tedious tasks and, on the other, they are criticized for causing unemployment. What should be the decision?

Ethical issues also arise from conflicts in deciding how best to use a technological innovation, or whether it would be better not to use it at all. The ongoing debate on nuclear energy, atomic warheads, the use of life support systems, the sale of various medicinal drugs, and pesticides are examples of problems that cannot be resolved by science alone.

In making ethical judgments in the sciences, we begin with an interpretation of empirical information that is based on research, or what is known of a technological innovation. Individuals are likely to differ in their perceptions of what the information means for resolving a human concern. Not everyone, for example, feels that a policy of "survival of the fittest" is the best way to balance human population with the food supply. Some people will contend that children should not be allowed to starve to death under any circumstances and that more money should be spent on agricultural research to solve the problem of food shortages.

Organization of the curriculum

To achieve its goals, the reform of science education will require that a substantial part of the curriculum be organized in terms of science/technology/societal problems, case studies, and historical presentations. If we expect students to develop intellectual skills associated with problem solving and decision making, we must give them the opportunities to learn these skills in terms of actual problems and issues. To become aware of how a technological achievement influences the culture and the lives of people, students can examine a science/technology achievement in a histori-

cal context. For example, they might study the impact of the automobile on transporation and life styles in America, the radio and television on communications, or antibiotics on the reduction of disease. Such studies will show how profoundly technology influences human affairs. Students can also study a science/technology-related problem in their local community, which would give them a chance to influence actions. Another approach would be to have students undertake a case study on the environmental impact of a new shopping center on a neighborhood or town.

Whatever the organization, there should be links with other basic subjects in the curriculum such as mathematics, social studies, and the humanities.

Science and vocational education

Reform in science education should also address the issues of vocational preparation. Changes in the nature of work in the United States have led to a greater emphasis on intellectual skills than manual skills for entering the job market. Today fewer than one out of three jobs is in the blue-collar or goods-producing sector of the economy. The productive capacity of individuals increasingly depends on a general ability to command, communicate, process, and use information.

The vocational competencies most needed today for men and women entering and advancing in a career include:

- an ability and motivation to learn through one's own efforts;
- a command of basic communication and expressive skills including reading, writing, speaking, listening, and computing;
- a command of cognitive skills such as decision making, problem solving, analyzing, synthesizing, conceptualizing, and evaluating that lead to good judgment.

These are the intellectual skills that are embedded in science programs that have a science/technology/society orientation. In addition, the technological topics in science courses provide students with a broad sense of what takes place in the world of work. They also provide students with an understanding of how career options are created, changed, or eliminated by technological innovations and processes such as robots, automation, and computers. With some idea in mind that changing job patterns are a way of life in a high technology society, students will realize that adjusting to new careers depends more on "intellectual technology" than on specific job skills.

The most effective workers in business and industry today possess good health, physical vigor, and a life-style consistent with

good hygiene. In a reformed science curriculum, courses in life and health would stress the importance of achieving and sustaining a high level of individual physical and mental health and vitality.

In addition, science teachers in all courses and at all grade levels should alert students to job opportunities and careers in the sciences and engineering. Nearly every section or major topic in a science course represents the career work of many people. For example, what is known about a cell is the result of careers in cell physiology, genetics, molecular biology, biochemistry, laboratory techniques, technologists who devise instrumentation, and many more. The proper presentation of science and technology as human endeavors includes not only describing the contributions made by researchers and engineers but identifying opportunities for new generations of students to advance what is now known.

Finally, science and technology taught in a personal and civic context should not neglect how these enterprises contribute to the productivity and progress of the nation. In addition, students should become aware that work is the central activity through which they participate in and contribute to society.

Science education and vocational education can no longer realistically be considered as separate endeavors in a modern scientific/technological society. Science courses cannot include all that young people should know about careers, jobs, and work; courses in the social sciences, English, and mathematics have contributions to make as well, as do specific vocational subjects related to local job markets.

Summary: Contrasting perspectives on science education

Much of the confusion on issues of science education in the United States today arises from a failure to recognize that the purposes of science education are changing, that new subject matter is being introduced, and that the context of the curriculum is shifting from that of the disciplines to human affairs. Current course offerings in the sciences limit their goals and subject matter to the "structure of disciplines."

The revitalization of science education is beginning to take form. While it is difficult to discern fully the nature of the reform, several characteristics are apparent. In the columns that follow, the new view of science education is identified and contrasted

with prevailing notions. The column on the left, "The Prevailing Framework," lists the dominant features of typical science education programs as they exist in schools today. The column on the right, "The Emerging Vision," lists the characteristics of a common education in science and technology. The columns should be read as a shift from the dominance of the attributes on the left toward a more balanced or new view on the right.

The Prevailing Framework

1. The rationale and goals are derived from the knowledge structure of individual science disciplines. The goals for teaching science are internal to the scholarly fields of scientific research.

2. The subject matter of school science courses is chosen from the professional information that charactizes the basic theories, concepts, and methodologies of selected science disciplines.

The Emerging Vision

1. The rationale and goals are derived from a consideration of how science and technology influence social well-being and human affairs. The goals for teaching science are based on scientific and technological systems in social, cultural, and individual contexts.

2. The subject matter of school science courses is chosen from science and technology in terms of its importance for understanding the role of science and technology in civic affairs, for promoting responsible citizenship, and for improving the quality of life.

3. The cognitive processes considered most important in science teaching are characteristically analytical, quantitative, theoretical, deductive, and value-free. These processes are taught in the context of simplified, preplanned laboratory experiments that respond to a linear style of problem solving. The problems selected for study are those internal to a science discipline. The focus is on the technique of the experiment and the accuracy of the results. Explanations of data are the product of deductive reasoning. The major goal is to portray inquiry skills in the process of scientific discovery.

3. The cognitive processes involved in the teaching of science and technology in social and human contexts are characteristically holistic, ecological, qualitative, inductive, value-ladened, complex, and involve decisions. These processes are taught in terms of multicausal, science-technology-social-based problems that typically require a systemic type of thinking. The problems selected for study are those that are common to human experience—both personal and civic. The focus is on how to resolve science-and-technology-based problems in the context of people, society, and the culture. The problems are seldom replicable and the reasonableness of the solution depends on the informed judgment of the investigator. Explanations of data are in probabilistic and functional terms, typical of problems embedded in human affairs and social systems. The primary intellectual skills emphasized are those associated with information processing and the use of knowledge.

4. Value and ethnical considerations reflect the conduct of scientific researchers, such as intellectual honesty; respect for the accuracy, pertinence, validity, and adequacy of quantitative data; appreciation of models, theories, and natural laws; and the unbiased reporting of research findings.

4. Questions of values and ethics have their origins in society and personal experience as well as in the achievements of science and technology. Ethical and value positions are viewed as judgmental interpretations of events or conditions based upon valid scientific and technological information. It is recognized that value positions and ethnical judgments are not fully stable but vary with their social and cultural setting and are influenced by new developments in the sciences and technology.

5. Textbooks serve as a source of both the achievements of science and the information considered desirable as preparation for careers in science and technical fields.

5. Textbooks serve as one source of valid information on current science/technology problems that are rooted in social, cultural, and personal affairs.

6. Science is taught in a way that will develop an understanding of the processes used by scientists to discover and to interpret the properties of the natural world. Each field of science represented in the school curriculum is taught in a way that will preserve its integrity as a discrete discipline.

6. Science and technology are taught in a way that will enhance an understanding of the natural world and develop an understanding of the interrelations among natural, technological, and social systems, including links with the humanities and behavioral sciences.